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Assessing the deformation at interfaces of flexible pavement under cyclic shear stresses

Saad Issa Sarsam[1✉], **Samah Abdulrazzaq AL Nuaimi**[2]

[1]Professor, Department of Civil Engineering, College of Engineering, University of Baghdad, Iraq
[2]MSc. Student, Department of Civil Engineering, College of Engineering, University of Baghdad, Iraq

✉**Corresponding author**
Professor, Department of Civil Engineering, College of Engineering, University of Baghdad,
Iraq
Email: saadisasarsam@coeng.uobaghdad.edu.iq

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ABSTRACT

Flexible pavement is usually constructed in multiple layers since the maximum thickness of a single hot mix asphalt layer is limited to that a roller can compact. Interfaces are often assumed to be fully bonded. However, this is often not the case. In this investigation, which was carried out during January to March 2020, an attempt has been made to assess the horizontal deformation at the interface bond under repeated shear stresses. Two types of tack coat (Rapid Curing cutback RC-70 and Cationic Medium setting emulsion CMS) and three application rates have been implemented in the preparation of two layers slab samples (base overlaid by binder, and binder overlaid by wearing) using roller compactor. Asphalt concrete core specimens were obtained from the roller compacted slab samples and subjected to 1200 cyclic shear stresses. The accumulation of permanent deformation was monitored. Afterwards, the specimens were tested for interface bond shear strength at 20 °C. It was concluded that the permanent microstrain for application rate (0.33)l/m^2 of RC-70 Tack coat and (0.23)l/m^2 of CMS Tack coat exhibit the lowest microstrain as compared to

other application rates regardless of the variation in asphalt concrete layers. It was recommended to implement RC-70 Tack coat on base or binder courses at a rate of 0.33 l/m^2 and CMS Tack coat on base or binder course at a rate of 0.23 l/m^2 to minimize permanent deformation. However, implementation of RC-70 and CMS on base courses at a rate of (0.33 and 0.23) l/m^2 and (0.15 and 0.1) l/m^2 on binder course is recommended to maximize interface bond shear strength.

Keywords: Deformation, Cyclic Shear, Interface, Bond, Asphalt concrete, Tack Coat

1. INTRODUCTION

In the design of flexible pavement, interfaces between pavement layers are often assumed to be fully bonded. However, this is often not the case. If the pavement layers are not completely bonded together, they cannot act as a single pavement layer. The ability of the pavement to bear loading and transfer the tensile and shear stresses from one layer to another effectively reduces significantly, (Kulkarni, 2004). Several premature failures such as (slippage and delamination) failures may take place as illustrated in Figure 1. Such type of failure happens due to improper bonding between the two asphalt concrete layers and the layers do not act together as one unites. Tack coat is usually implemented to increase the adhesion between two layers. The most vulnerable locations of occurrences of premature failure are where traffic is accelerating or decelerating and on horizontal curves. Mohammad et al., 2002 evaluated the practice of using tack coat through controlled laboratory shear tests and determined the optimum application rate. The influence of tack coat types, their application rates, and the testing temperatures on the interface shear strength of pavement layers was examined. Sudarsanan et al., 2015 stated that the performance of the interface system depends mainly upon the bonding with the existing layer as well as with the overlay layer. Different type of bond testing methods based on the stresses developed at the interface have been investigated and the factors that influence the bonding due to the presence of the geosynthetic as an interlayer in the performance of asphalt pavement were evaluated. Jaskuła, 2014 reported that interface bond strength between the asphalt concrete layers depended strongly on the applied compaction technique, as well as the compaction effort. It was concluded that efficient compaction may produce a maximum shear force without tack coat. The type of emulsion used as the tack coat was also found to be highly relevant to the interface bonding. Coleri et al., 2017 stated that high tensile and shear stresses are created by truck loadings which can break the bond between the two asphalt concrete layers when the applied stresses exceed the shear and tensile strength of the tack coat. When the bond between two asphalt concrete layers is broken, both layers start to act as independent layers. This change in the pavement structure scheme can shift the critical strain location from the bottom of the asphalt concrete structure to the poor bonded location, (Mohammad et al. 2012).

Figure 1 Premature Failure Due to Bond Interface, (Kulkarni, 2004)

As stated by (Raab, 2011), the bond between asphalt concrete pavement layers does not depend only on the adhesion properties of the binder but also on the interlock forces, and therefore on the geometrical surface texture conditions of the interface between the two pavement layers. Swarna and Hossain, 2018 stated that when there is an increase in interface bond strength, the strains corresponding to the high fatigue life of the pavement at the bottom of the asphalt concrete layer are reduced. However, when the optimum application of the tack coat is implemented, the smooth interface generated can provide better bonding. On the other hand, an overlay without any interface bonding (tack coat) will lead to the premature cracking of pavement. Raab and Partl, 2009 stated that inadequate interface condition can lead to the redistribution of stresses and strains in the pavement structure which has been considered as a major cause of premature failure for road structures. It was reported that the principal types of distress, such as slippage, delamination, and top-down cracking, are due to the asphalt emulsion quality, its application rate and its capacity to bond asphalt concrete layers. It was concluded that when the adhesion at the interface between coats is low, the binder tends to

crack early under repeated loading with increased rutting due to the internal energy consumption of the material, resulting in fatigue problems and top-down cracks.

Methodology

The aim of the present investigation, which was conducted during January to March 2020, is to assess the deformation at the interface of asphalt concrete layers under cyclic shear stresses. The influence of tack coat type and application rates on the interface bond shear strength will also be accessed through an intensive laboratory work.

2. MATERIALS AND METHODS

All the materials used in this investigation are locally available and widely implemented in road construction.

Asphalt Cement

The asphalt cement of penetration grade of 40-50 is brought from Dura refinery and implemented in this investigation. The physical properties of the asphalt cement are demonstrated in Table 1.

Table 1 Physical Properties of Asphalt Cement

Test	Test condition	ASTM,2013 Designation	Units	SCRB, 2003 Specification	Test result
Penetration	100gm, 25C°, 5 sec (1/10mm)	D-5	1/10mm	40-50	46.5
Specific Gravity	@ 25 °C	D-70	gm/cm^3	--------	1.05
Flash point	___Cleveland open cup	D-92	°C	>232	285
Ductility	25 °C, 5cm / min	D-113	cm	>100	>150
Softening point	Ring and ball	D-36	°C	-------	48
Kinematic viscosity	@135°C	D2170	C. Stoke	--------	230
Residue after thin film oven test					
Penetration of residue	100gm, 25C , 5 sec (1/10mm)	D 5	1/10mm	40 – 50	36.5
Ductility of residue	25 °C, 5cm / min	D113	cm	>55	145
Loss in weight	5 hours at 163 C°,50 gm	D 1754	%	<0.75	0.13

Cut Back Asphalt

Rapid curing cut back RC-70, which is widely used in Iraq, is implemented as tack coat. The physical properties of the RC-70 are presented in Table 2. Three application rates of (0.15, 0.33, 0.5) liter/m^{2}have been tried which are within the limitations of state commission for roads and bridges (SCRB, 2003).

Table 2 Physical Properties of RC-70 Cut Back

Test	ASTM, 2013 Designation	Cut Back Asphalt	Specification Limits ASTM, 2013	
			Minimum	Maximum
Density (gm/liter)	D2028, D3142	995	---	---
Water concentration (%)	D95	0.1%	---	0.2%
Residual byEvaporation(%)	D2028	90%	55%	---
Kinematic viscosity (C. Stoke)	D2170	75	70	95

Cationic Emulsion

Medium setting cationic emulsion CMS has been implemented as tack coat. The physical properties of emulsion are illustrated in Table 3. Three application rates of (0.1, 0.23, 0.35) liter/m^{2}have been tried which are within the limitations of state commission for roads and bridges (SCRB, 2003).

Table 3 Physical Properties of Emulsion

Property	ASTM, 2013Designation	Test Result	Limits
Emulsion type	D2397	Cationic (CMS)	Medium setting
Residue by evaporation %	D6934	54	Min 40
Specific gravity,gm/cm^3	D70	1.04	-------
Penetration (mm)	D5	219	100 - 250
Ductility(cm)	D113	46	Min 40
Viscosity, Saybolt-Furol viscometer @ 50 °C – AASHTO, 2013	AASHTO M208	348	110 - 990
Solubility in Trichloroethylene (%)	D2042	97.7	Min 97.5
Emulsified asphalt / job aggregate coating practice	D244	Fair	Good

Coarse Aggregate

The uncrushed coarse aggregates were implemented for base course layer while crushed coarse aggregates were used for binder and wearing course layers. Coarse aggregates are obtained from AL-Nibaee quarry. The nominal maximum size of coarse aggregate ranges between (25 mm) and retained on sieve No. 4 (4.75mm) according to (SCRB, 2003) specification. The physical properties are shown in Table 4.

Fine Aggregate

Crushed and river sand fine aggregate were obtained from AL-Nibaee quarry. The fine aggregate ranges between 4.75mm (No.4) sieve and retained on 0.075mm (NO.200) sieve according to (SCRB, 2003) specifications. The physical properties of the fine aggregates are shown in Table 4.

Table 4 Physical Properties of Aggregates

Property	Coarse Aggregate	Fine Aggregate	SCRB, 2003 Limitations
Bulk Specific Gravity(ASTM C-127 and C128)	2.61	2.632	---------
Apparent Specific Gravity (ASTM C127and C128)	2.657	2.693	---------
Percent Water Absorption (ASTM C-127 and C128)	0.443	0.526	5 % Max.
Percent Wear (Loss Angeles Abrasion)(ASTM C-131)	18.6	--------	35 - 45
Percent Sand equivalent D2419	---------	55	45 min
Angularity for coarse aggregate ASTM D5821	96%	-------	90 min
Percent flat and elongated particles D4791	Flat	3%	<10%
	Elongation	5%	5 - 1

Mineral Filler

Ordinary Portland cement is implemented as mineral filler. The physical properties are shown in Table 5.

Table 5 PhysicalProperties of Portland cement Filler

Property	Test Result
%passing Sieve No.200(0.075mm)	97
Specific Gravity, gm/cm^3	3.14
Specific Surface Area (m^2/kg)	310.5

Combined Gradation of Asphalt Concrete

The coarse and fine Aggregates used in this study were sieved and recombined in the proper proportions to meet the Base, binder, and Surface course gradations. Figure 2 exhibit the aggregates gradations used to prepare mixtures for wearing, binder and, base courses respectively as per (SCRB, 2003).

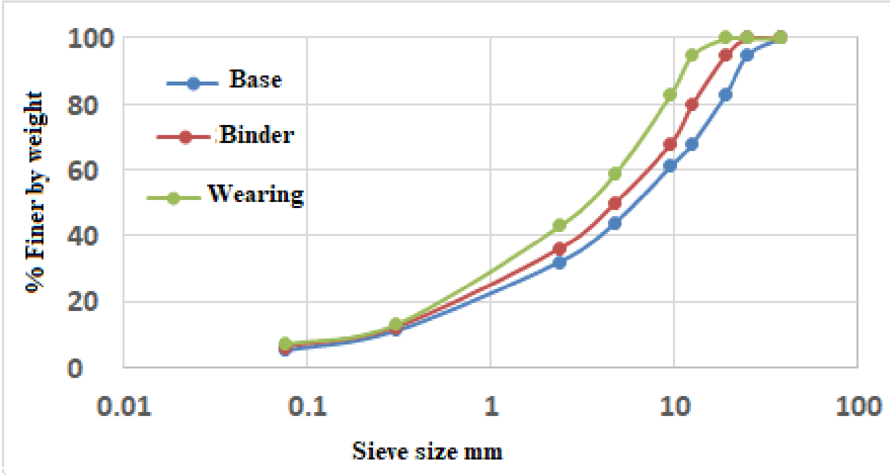

Figure 2 the Aggregate Gradation According to SCRB, 2003

Preparation of Asphalt Concrete Mixtures

The aggregates were oven dried to a constant weight at 110ºC, then sieved to different sizes, and stored separately. Coarse and fine aggregates were combined with mineral filler to meet the specified gradation of asphalt concrete layers as per (SCRB, 2003) specifications. The combined aggregate mixtures were heated to 150ºC before mixing with asphalt cement. The asphalt cement was heated to the same temperature of 150ºC, then it was added to the aggregate to achieve the desired amount and mixed thoroughly using mechanical mixer for two minutes until all aggregate particles were coated with thin film of asphalt cement. Marshall Size specimens were prepared in accordance with (ASTM D1559, 2013) using 75 blows of Marshall Hammer on each face of the specimen for binder and wearing course mixtures. However, 50 blows of Marshall Hammer on each face of the specimen for base course mixture were used. Specimens were tested for Marshall and volumetric properties, and the optimum asphalt content for each mixture was obtained.

Preparation of Asphalt Concrete Slab Samples and Core Specimens

Two types of asphalt concrete Slab specimens of (400 mm by 300 mm) were prepared using the roller compactor. The first type consists of base course of 80 mm thickness overlaid with binder course of 40 mm thickness. The second type consists of binder course of 60 mm overlaid with wearing course of 40 mm. Pneumatic Roller Compactor B3602-DYNA, was implemented to prepare slab samples. Roller compaction was adopted as per (EN12697-33, 2007) with a static load start from 2.4 kN for 10 cycles. The load was increased each 10 cycles to reach 9.1 kN for a total of 33 cycles to meet the target density of the layers at their optimum asphalt content. The compaction temperature was maintained to 135 °C.

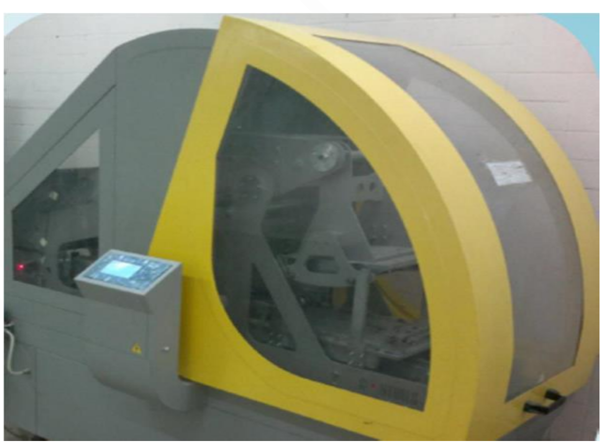

Figure 3 The Roller Compactor Implemented

Figure 4 Part of the Prepared Slab Samples

Figure 3 shows the roller compactor implemented. After the base course slab of the first type or the binder course slab of the second type were compacted, the slabs were left for 24 hours to cool at laboratory environment. Then the compacted slabs for each

type were subjected to tack coat application at the specified application rate and tack coat type. Samples were left for 120 minutes to cure the tack coat, then overlaid by binder or wearing course mixtures and subjected to the roller compaction to the target density as explained above. Slab samples were left for 24 hours at the laboratory environment to cool. Afterward, six Core specimens of 110 mm diameter were cut by the Diamond saw to the full depth of the slab which consists of two courses of asphalt concrete. The total number of slab samples prepared was 12 while, the total number of core specimens was 72. Figure 4 exhibits part of the prepared slab samples, while Figure 5 shows part of the obtained core specimens.

Figure 5 Part of the Core Specimens Obtained

Interface Cyclic Shear Stress test

Shear test device consist of testing mold which was designed and manufactured at local market and implemented to evaluate interface shearstrength. The test involves the application of a direct cyclic shearstress and the resulting horizontal shear displacement during the test was monitored. The mold and the asphalt concrete specimenare placed in an environmental chamber capable of controlling the temperature to within 20±0.5°C. The test mechanism is such that one layer is held stationary in the mold while the other layer is loaded with a specific shear displacement rate. The specimens that were used in this study had a diameter of 110 mm and variable length of (100-120) mm based on testing combination of pavement layers. Specimens were seated in the pneumatic repeated load system PRLS chamber.

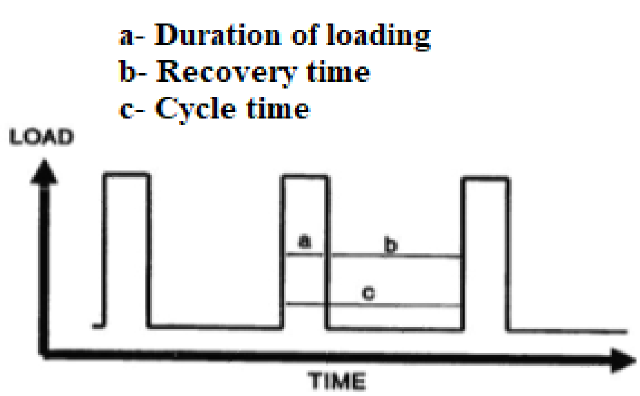

Figure 6 Interface Bond Shear Strength Mold

Figure 7 Cyclic Shear stress loading sequence

The cyclic shear stress test as specified by (Sarsam and Abdulhussain, 2019) was conducted. The test was performed on core specimens, 110 mm in diameter and variable length. Cyclic shear loading was applied to the diametral specimen and the vertical strain is monitored under the load repetitions. Diametral loading is applied with a constant loading frequency of 60 cycles per minute and loading sequence for each cycle is 0.1 sec load duration and 0.9 sec rest period. Cyclic Stresses were applied under

constant stress level of 0.138 MPa, while the testing temperatures of 20 ºC were maintained throughout the test. Specimens were subjected to the application of cyclic shear stresses for 1200 repetitions. Figure 6 exhibit the Interface Bond Shear Strength Testing mold. Figure 7 exhibit the cyclic load sequence implemented, while Figure 8 shows the PRLS and the cyclic shear stress test setup.

After 1200 load cycles, the test was terminated. The core specimens and the testing mold were transferred to the versa testing machine shown in Figure 9. The specimens were tested for bond shear strength. Testing was conductedat 20°C at a constant loading rate of5 mm/min. The interface bond shear strength is calculated by dividing the maximum load sustained by the specimen before failure by the cross-sectional area of the specimen. Similar testing mold and procedures were reported by (Zhang, 2017); (Biglari et al., 2019); and (Mirsayar et al., 2017).

Figure 8 PRLS and the cyclic shear stress test

Figure 9 Interface Bond Shear Strength Testing

3. RESULTS AND DISCUSSION

Influence of RC-70 tack coaton Permanent Deformation

Figure 10 exhibit the impact of RC-70 tack coat application rate on the permanent microstrain at the interface of asphalt concrete core specimens while practicing 1200 cyclic shear stresses. It can be observed that the permanent microstrain for application rate (0.33)l/m^2 exhibit the lesser value of microstrain as compared to application rates of (0.15, 0.5)l/m^2 regardless of the variation in asphalt concrete layers.

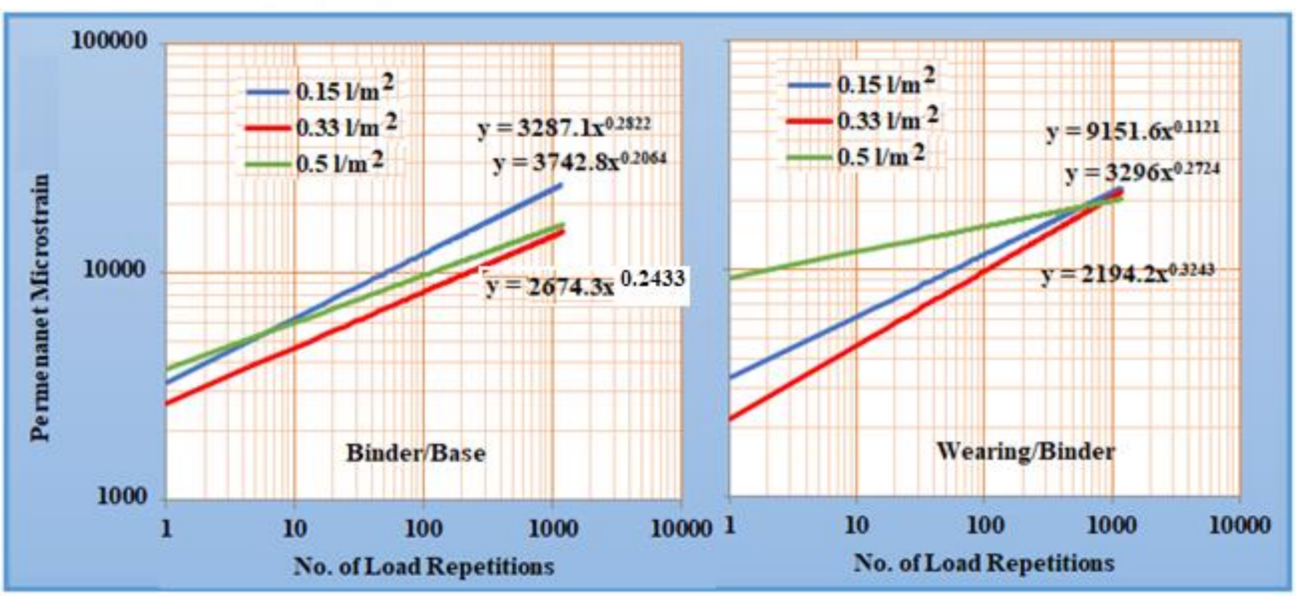

Figure 10 Impact of RC-70 tack coat application rate on Permanente micro strain

However, as the application rate of tack coat increases, the rate of increases in permanent deformation decreases as compared to 0.15 l/m^2 application rate. On the other hand, as the tack coat application rate increases, the permanent microstrain increases. This could be attributed to the more flexible binder added to the interface.

Table 6 illustrates the influence of RC-70 tack coat on the permanent deformation parameters at the interface of asphalt concrete layers. It can be noted that the intercept which represents the permanent microstrain at N=1 (N is the number of load cycles) increases by (89.2 and 40) % when the RC-70 tack coat application rate changes to (0.15 and 0.5) l/m^2 respectively for the interface of base course overlaid by binder course. On the other hand, the intercept increases by (50.2 and 320) % when the RC-70 tack coat application rate changes to (0.15 and 0.5) l/m^2 respectively for the interface of binder course overlaid by wearing course. In fact, as the value of the intercept gets higher, it indicates a larger strain and potential of permanent deformation. However, the slope, which refers to the rate of change in the permanent microstrain decreases by (14.5 and 27) % when the RC-70 tack coat application rate changes to (0.15 and 0.5) l/m^2 respectively for the interface of base course overlaid by binder course. On the other hand, the slope decreases by (16 and 69) % when the RC-70 tack coat application rate changes to (0.15 and 0.5) l/m^2 respectively for the interface of binder course overlaid by wearing course. The slope is referred as a function of the change in loading repetitions and rate of strain. High slope of the mixture indicates an increase in the material deformation rate, hence, less resistance against rutting. A mixture with low slope is preferable as it prevents the occurrence of rutting, (Sarsam and Jasim, 2018).

Table 6 Influence of RC-70 Tack Coat on the Permanent Deformation Parameters at the Interface

Tack coat type	Bottom layer	Top layer	Stress level (KPa)	Application rate	Intercept	Slope	Microstrain
RC-70	Base course	Binder course	137.895	0.15	3287.1	0.2422	25200
				0.33	2674.3	0.2833	16400
				0.5	3742.8	0.2064	18600
	Binder course	Wearing course		0.15	3296	0.2724	23000
				0.33	2194.2	0.3243	22400
				0.5	9216.6	0.0995	23500

Influence of CMS tack coaton Permanent Deformation

Figure 11 exhibit the impact of CMS tack coat application rate on the permanent microstrain at the interface of asphalt concrete core specimens while practicing 1200 cyclic shear stresses. It can be observed that the permanent microstrain for application rate (0.23) l/m^2 exhibit the lesser value of microstrain as compared to application rates of (0.11, 0.35)l/m^2 regardless of the variation in asphalt concrete layers.

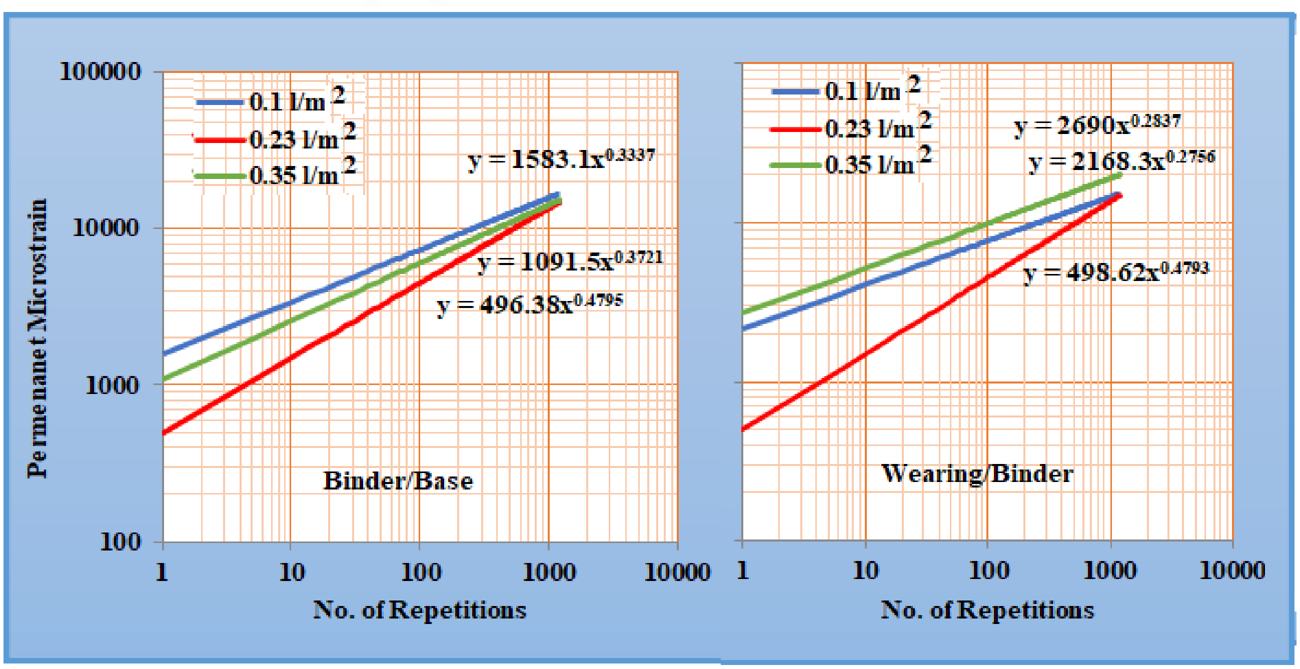

Figure 11 Impact of CMS tack coat application rate on Permanente micro strain

However, as the application rate of tack coat increases, the rate of increases in permanent deformation decreases as compared to 0.23 l/m^2 application rate. On the other hand, as the tack coat application rate increases, the permanent microstrain increases. This could also be attributed to the more flexible binder added to the interface.

Table 7 illustrates the influence of CMS tack coat on the permanent deformation parameters at the interface of asphalt concrete layers. It can be noted that the intercept increases by (219 and 120) % when the CMS tack coat application rate changes to (0.1 and 0.35) l/m^2 respectively for the interface of base course overlaid by binder course. On the other hand, the intercept increases by (335 and 440) % when the CMS tack coat application rate changes to (0.1 and 0.35) l/m^2 respectively for the interface of binder course overlaid by wearing course. However, the slope decreases by (30.4 and 22.3) % when the CMS tack coat application rate changes to (0.1 and 0.35) l/m^2 respectively for the interface of base course overlaid by binder course. On the other hand, the slope declines by (42.5 and 41) % when the CMS tack coat application rate changes to (0.1 and 0.35) l/m^2 respectively for the interface of binder course overlaid by wearing course.

Table 7 Influence of CMS Tack Coat on the Permanent Deformation Parameters at the Interface

Tack coat type	Bottom layer	Top layer	Stress level (KPa)	Application rate	Intercept	Slope	Microstrain
CMS	Base course	Binder course	137.895	0.1	1583.1	0.3337	18600
				0.23	496.38	0.4795	15900
				0.35	1091.5	0.3721	16400
	Binder course	Surface course		0.1	2168.3	0.2756	17500
				0.23	498.62	0.4793	15300
				0.35	2690	0.2837	20800

Influence of Cyclic Shear Stress on the Bond Shear Strength of Asphalt Concrete

As illustrated in Figure 12, the interface bond shear strength IBSS may vary between two layers, depending on the type and the texture of the bottom layer sample as reported by (Huang et al., 2015). Increasing the coarseness of texture can result in increased interface bond shear strength. The Figure demonstrates the influence of application rate and tack coat type on the interface bond shear strength. It can be observed that for RC-70 cutback, the asphalt concrete binder course laid on base course exhibit the highest shear strength of 1600 kPa at an application rate of 0.33 liter/m^2 when compared to other application rates. When the application rate increases, the shear strength decreases. This could be attributed to the excess asphalt film with more lubrication ability which reduces the required friction and particles interlock.

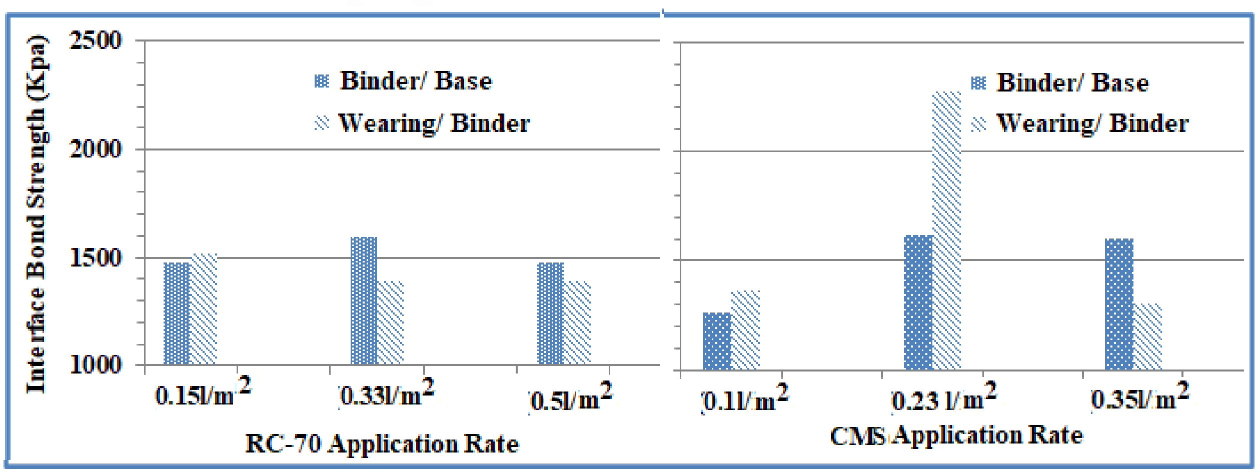

Figure 12 Influences of Application Rate and Tack Coat Type on IBSS.

However, the asphalt concrete wearing course laid on binder course exhibit the highest shear strength of 1515 kPa at an application rate of 0.15 liter/m^2 when compared to other application rates. On the other hand, when cationic emulsion was implemented as tack coat, the asphalt concrete binder course laid on base course exhibit the highest shear strength of 1620 kPa at an application rate of 0.23 liter/m^2 when compared to other application rates. However, the asphalt concrete wearing course laid on

binder course exhibit the highest shear strength of 2272 kPa at an application rate of 0.23 liter/m^2 when compared to other application rates. It can be observed that in general, both RC-70 and CMS tack coat exhibit higher IBSS with coarse surface texture as compared to the case of fine surface texture regardless of the application rate adopted. On the other hand, RC-70 tack coat exhibit higher IBSS for fine surface texture as compared to CMS tack coat. Table 8 summarizes the influence of tack coat type and application rate on the interface bond shear strength.

Table 8 Interface Bond Shear Strength

Tack Coat	Application rate l/m^2	Interface shear strength (kPa) binder/base	Interface shear strength (kPa) wearing/binder
CMS	0.1	1262.7	1367.9
	0.23	1620.5	1272.8
	0.35	1599.4	1304.7
RC-70	0.15	1473.2	1515.3
	0.33	1599.4	1388.9
	0.5	1473.2	1388.9

4. CONCLUSIONS

Based on the limitations of materials and testing, the following conclusions are drawn.

1. The permanent microstrain for application rate (0.33)l/$m^2$of RC-70 Tack coat and (0.23)l/m^2 of CMS Tack coat exhibit the lowest microstrain as compared to other application rates regardless of the variation in asphalt concrete layers.
2. The asphalt concrete binder course laid on base course exhibit the highest shear strength of 1600 kPa at an application rate of 0.33 liter/$m^2$of RC-70 Tack coat when compared to other application rates. However, asphalt concrete wearing course laid on binder course exhibit the highest shear strength of 1515 kPa at an application rate of 0.15 liter/m^2 when compared to other application rates.
3. The asphalt concrete binder course laid on base course exhibit the highest shear strength of 1620 kPa at an application rate of 0.23 liter/m^2 of CMS Tack coat when compared to other application rates. However, the asphalt concrete wearing course laid on binder course exhibit the highest shear strength of 2272 kPa at an application rate of 0.23 liter/m^2 when compared to other application rates.
4. It is recommended to implement RC-70 Tack coat on base or binder courses at a rate of 0.33 l/m^2 and CMS Tack coat on base or binder course at a rate of 0.23 l/m^2 to minimize permanent deformation.
5. It is recommended to implement RC-70 and CMS on base courses at a rate of (0.33 and 0.23) l/m^2 and (0.15 and 0.1) l/m^2on binder course to maximize interface bond shear strength.

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